(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: 0 374 115 A1

(12) EUROPEAN PATENT APPLICATION

(21) Application number: 89850427.9

(22) Date of filing: 08.12.89

(51) Int. Cl.⁵: F04B 43/02

(30) Priority: 08.12.88 SE 8804448
30.05.89 US 359085

(43) Date of publication of application:
20.06.90 Bulletin 90/25

(84) Designated Contracting States:
AT BE CH DE ES FR GB GR IT LI LU NL SE

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(54) Positive displacement pump.

(57) A positive displacement pump comprises a variable volume pump chamber (16-1) and a drive mechanism (26-1) having a displacement member (25-1) for reducing the volume of the pump chamber(16-1). Fluid enters the pump chamber (16-1) from a supply chamber (15-1) located adjacent to and surrounding the lateral outer boundary of the pump chamber (15-1) through a valve-controlled inlet passage (17-1) that opens to the pump chamber (16-1) at an elongated gap-like inlet opening. The inlet passage permits fluid to flow from the supply chamber (15-1) into the pump chamber (16-1) with substantially no pressure drop.

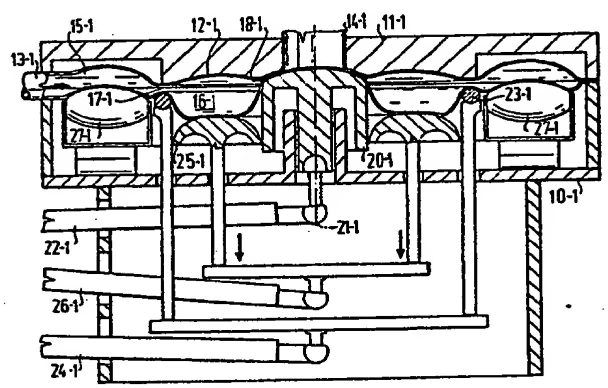

FIG.1A

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Positive Displacement Pump

Background of the Invention

Most positive displacement pumps - i.e., pumps which have a variable volume pump chamber that includes a movable displacement element - admit and discharge the fluid through ports opening to the chamber through a non-movable chamber wall. The inlet and outlet ports ordinarily have one-way valves, such as ball check valves or flap valves. Because of limited space available for the ports and the fact that the limiting factor in pumping capacity is ordinarily in the piping to and from the pump rather than in the pump itself, the inlet and outlet ports are relatively small. The small size of the ports restricts intake and delivery flow rates, creates pulsating inflow and outflow and consumes energy in the form of dynamic fluid friction and turbulence losses. Also, the relatively small size of the inlet ports in most pumps requires a relatively high pressure difference between the inlet and the pump chamber to ensure filling during the intake stroke.

The inventor of the present invention has done considerable work for several years on the development of blood pumps for replacing or supplementing the anatomical heart in pumping blood through the vascular system. There are several characteristics required for blood pumps that are not easily met. For one thing, it is desirable that a mechanical blood pump be capable of taking in blood essentially continuously, preferably with a minimum amount of pulsation. Second, a mechanical blood pump should have the ability to adjust its output automatically to changes in input over a fairly wide range. Third, a blood pump, including the valves, must be as free as possible from "dead spaces"; spaces where there is little or no flow and where, consequently, blood can collect and form clots; the blood must be kept moving throughout the pump at all times. Fourth, a blood pump must be sterile and free of toxic materials when put into use and must remain so as long as it is in use.

Mechanical blood pumps for temporary use, such as during open heart surgery or to assist a damaged heart for a short time while it heals, are being used increasingly. The mechanical heart pumps in current use only partly meet the recognized requirements. For example, they have little ability to adjust automatically to changes in the body's requirements for blood and, instead, have to be closely monitored and controlled. Present mechanical blood pumping systems require that a relatively large amount of the patient's blood flow outside the body, and an amount of blood equal to that outside the patient's body must be added, which is undesirable.

Lundbäck U.S. Patent No. 4,648,877 (March 10, 1987) describes and shows a blood pump that meets very effectively the above-mentioned requirements. The pump of that patent has a supply (atrium) chamber and a pump (ventricle) chamber joined by a short passage containing a one-way valve. The chambers are formed of a flexible, substantially non-extensible material and can be made relatively inexpensively and thus can be replaced in cases of use by different patients outside the body. A drive ring is driven in a direction to reduce the volume of the pump chamber, i.e., to pump blood from the pump chamber, and is moved in the opposite direction for intake of blood in response to inflow of blood from the supply chamber. The design of the pump of the Lundbäck patent is such that there are no dead spaces where the flow is relatively quiescent and blood can collect and form clots. While restrictions on flow are minimized, the pump has three relatively small ports, two of which have a one-way valve.

Summary of the Invention

One object of the present invention is to provide a positive displacement pump that has small hydraulic flow losses. Another object is to minimize the pressure drop across the pump intake and thereby ensure rapid flow to the pump chamber, even with a very low differential pressure across the inlet to the pump chamber. Ancillary to the latter object is a minimizing of pulsation in the flow upstream from the pump, both when the intake is closed (a back-pressure pulsation) and when it is open (an induction pulsation). In this respect, it is desired that one-way valves which are capable of closing reliably substantially without having to be subjected to, and without causing, backflow should be provided, so that shocks resulting from backflow are avoided. It is also intended to simplify and to minimize the costs of replaceable components of a pump, i.e., all conduits, chambers and valves through which the blood (or other fluid) flows and which are preferably, therefore, not reused. Still another object is to provide a pump that automatically adjusts its output to the input and that requires a minimum quantity of fluid within the pump.

The foregoing and other objects are attained, according to the invention, by a positive displacement pump that, like the pump of the aforementioned Lundbäck patent, includes a supply chamber for receiving the fluid to be pumped, a variable volum pump chamber, an inlet passage through

which the fluid is conducted from the supply chamber to the pump chamber and an outlet through which the fluid is discharged. A displacement member associated with the pump chamber is movable in opposite directions along a predetermined path such as to move through a variable displacement zone of the pump chamber to increase and decrease alternately the volume of the chamber. A drive mechanism moves the displacement member in at least a direction to decrease the volume of the pump chamber. An inlet valve closes the inlet passage to block fluid backflow out of the pump chamber through the inlet passage.

According to the present invention, the supply chamber is disposed generally laterally of and substantially surrounds the displacement zone of the pump chamber, and the inlet passage is substantially coextensive with the supply chamber and opens to the pump chamber through an elongated gap-like opening in a bounding wall of the pump chamber located laterally of the displacement zone, whereby fluid may enter the pump chamber through the inlet passage substantially without any pressure drop. Preferably, the pump chamber includes a movable wall member that is engageable by the displacement member on the delivery stroke and disengageable from the displacement member during the intake stroke so that the stroke volume of the pump is established by the inflow of the fluid through the intake passage. It is usually advantageous to make the pump chamber generally round (circular or oval) with a diameter substantially greater than the height.

According to another aspect of the invention, one wall of the pump chamber transverse to the direction of movement of the displacement member is formed of a flexible material and is engaged and deflected by the displacement member through the displacement zone to decrease the volume of the chamber. One wall of the inlet passage may also be of flexible material and, preferably, be integral with the transverse wall of the pump chamber. One form of inlet valve includes a movable pinch valve member that engages and moves the flexible wall at the inlet passage across the inlet passage into engagement with the opposite wall, or with a flap valve, thereby closing the opening. Alternatively, the inlet valve may be a flap of flexible material attached at one of its edges to one wall of the inlet passage and having its other end free such that it responds to fluid flow and/or pressure by opening on the intake stroke of the pump chamber and closing on the pumping stroke by engaging the other wall of the passage or by engaging a similar fl xible flap attached to the other wall of the inlet passage.

In some embodiments, the pump chamber has an outlet in the form of a port, and an outlet valv for the outlet port makes use of the flexible pump chamber wall and a movable valve member that displaces the flexible wall into engagement with the outlet port, thereby closing it. Other forms of valves, such as flap valves, can be used on the outlet from the pump chamber. It is also possible to omit an outlet valve altogether.

Advantageously, the supply chamber, inlet passage and pump chamber are defined by two sheets of flexible material supported by such rigid back-up members as are required for carrying weight and sustaining forces due to pressure. The sheets of material are pre-formed to define the walls of the pump chamber, supply chamber and inlet passage and are joined in sealed relation at their outer perimeters. The rigid back-up members define the shapes at maximum volumes of the chambers and shape the inlet opening to the pump chamber.

The preferred annular and circular forms of the supply chamber and pump chamber provide for deflections of the pump chamber flexible wall with a minimum of wrinkling and provide for uniformity of fluid flow radially into the pump chamber. With an outlet disposed axially opposite the displacement member, uniform outflow, radially and then axially, is ensured. In the circular form, the flow through the pump occurs at low levels of turbulence, but at relatively high velocities, with no quiescent regions.

The invention also includes embodiments having a second stage variable volume chamber that receives fluid from the pump chamber during the delivery stoke of the latter. Part of the fluid delivered by the pump chamber during its delivery stroke passes through the second stage chamber to a discharge passage while the rest is inducted during the intake stroke of the second stage chamber, which preferably operates in phase opposition to the pump chamber. In this way, fluid is discharged from the pump substantially continuously, i.e., during both the intake and delivery strokes of the second stage, and pulsations in the delivery are reduced.

The preferred chamber element - pre-formed sheets of flexible material joined together in sealed relation at their perimeters - can be produced at low cost and is easy to install in a support structure. It is, therefore, economically and practically advantageous for the chamber element to be a disposable component.

For a better understanding of the invention, reference may be made to the following description of exemplary embodiments, taken in conjunction with the figures of the accompanying drawings.

Description of the Drawings

Figs. 1A to 7A are generally diagrammatic cross-sectional views of seven embodiments of single stage pumps shown in their configurations during the intake stroke;

Figs. 1B to 7B are generally diagrammatic cross-sectional views of the respective embodiments of Figs. 1A to 7A shown during their delivery strokes;

Fig. 6C is a plan view of the chamber element of the embodiment of Figs. 6A and 6B;

Fig. 7C is a diagrammatic cross-sectional view of the embodiment of Figs. 7A and 7B at the end of the intake stroke;

Figs. 8a and 8B are diagrammatic cross-sectional views of a two-stage pump embodying the invention at different stages of its operation;

Figs. 9A and 9B are views similar to Figs. 8A and 8B showing a modified two-stage pump;

Figs. 10A and 10B are diagrammatic cross-sectional views of a further two-stage pump embodying the invention at different stages of its operation, corresponding to the stages shown in Figs. 8A, 9A and 8B, 9B, respectively; and

Fig. 10C is a plan view of the chamber element of the embodiment of Figs. 10A, 10B.

Corresponding parts of all of the embodiments are designated by the same reference numerals followed by a hyphen (-), and a number following the hyphen corresponding to the Figure number, which makes the complete numeral distinctive to the particular embodiment.

Description of the Embodiments

In all of the embodiments shown in the drawings, the surfaces contacted by the liquid being pumped are the internal surfaces of a discoid, generally circular or partly circular disposable chamber element having an inlet and an outlet and made of a flexible but substantially non-extensible material, such as polyethylene, polyurethane or other plastic film. In other, non-disclosed embodiments some or all of these surfaces may, however, be surfaces of stationary and movable pump elements of metal, for example, which are permanent parts of the pump. Also, the chamber element does not have to be circular.

As shown in Figs. 1A,1B, the pump has a housing comprising a fixed base member 10-1 and a removable or hinged top member 11-1. The discoid chamber element is designated 12-1 and is interposed between the base member and the top member. At its perimeter the chamber element 12-1 has an inlet connection 13-1, and at its center it has an upstanding axial outlet connection 14-1.

The element 12-1 has an annular supply chamber 15-1 into which the inlet connection 13-1 opens. Within the supply chamber is a pump chamber 16-1 which communicates along its lateral bounding wall portion with the supply chamber 15-1 through an inlet passage 17-1 in the form of an endless annular gap-like opening between the opposed element walls. The pump chamber 16-1 communicates with the central outlet connection 14-1 through an outlet passage 18-1 which is also formed by an endless annular gap.

The element 12-1 may be made of any flexible material possessing the properties required for the specific use of the pump in each particular case. Naturally, the material should be compatible with the liquid to be pumped and sufficiently flexible, durable and difficult to extend to endure the pressure and the mechanical and, as the case may be, thermal stress imposed on it.

The housing base member 10-1 supports various movable components on which the element 12-1 rests and which bring about the pumping by their repetitive or cyclical movements. These components comprise a centrally positioned outlet valve member 20-1 which serves to open and close the outlet passage 18-1 to permit flow between the pump chamber 16-1 and the outlet connection 14-1. The outlet valve member is movable vertically parallel to the central pump axis 21-1 so as upon its upward movement to pinch the opposed element walls against the housing top member 11-1 and thereby close the outlet passage 18-1, and so as upon its downward movement to allow the element walls to move apart so that the outlet passage is opened. The movements of the outlet valve member 20-1 are derived from a lever 22-1 which in turn is actuated by a cam or other suitable drive member (not shown) and associated motor.

There is also an inlet pinch valve member 23-1 which operates in a manner similar to the outlet valve member 22-1 to open and close the inlet passage 17-1. The inlet valve member 23-1 is annular, and its upward and downward movements are derived from a lever 24-1 which in turn is actuated in synchronism with the lever 22-1 by a motor-driven cam (not shown).

Between the valve members 20-1 and 23-1 and opposite the pump chamber 16-1, an annular displacement member 25-1 is provided which is moved vertically up and down by means of a lever 26-1 and a motor-driven cam (not shown) in a manner similar to the valve members, and in synchronism therewith. The displacement member 25-1 serves upon its upward movement to displace positiv ly the low r pump chamber wall to thereby reduce the volume of the pump chamber 16-1 and upon its downward movement allow the pump chamber to expand as fluid flows into the pump chamber.

In the embodiments of Figs. 1A and 1B there is

also a pair of rollers 27-1 which are positioned below and in engagement with the supply chamber 15-1 of the element 12-1. In operation of the pump, these rollers, which may be more than two in number, are orbited circumferentially along the supply chamber by means not shown to keep all liquid in the supply chamber in constant movement. Such agitation of the liquid may be necessary or advantageous in certain applications, e.g. when the liquid is blood.

In operation of the pump, the supply chamber 15-1 acts as a reservoir, the volume of which is changed in dependence on the inflow and which continuously receives liquid under relatively low pressure through the inlet connection 13-1. In the phase of the pump cycle shown in Fig. 1A, where the inlet passage 17-1 is open and the displacement member 25-1 is moving downwardly or has just reached its lowermost position, liquid flows from the supply chamber 15-1 into the pump chamber 16-1 through the inlet passage 17-1. Filling of the pump chamber may take place very rapidly, because the inlet passage is very long, i.e. has a very large circumferential extent, and can readily be opened over a relatively substantial height. In other words, the inlet passage can readily be opened to present a very large cross-sectional area to the flow. Also, because the supply chamber and inlet passage surround most or all of the perimeter of the pump chamber and fluid enters radially from all directions, the filling length, i.e. the distance the liquid has to flow to fill the pump chamber, is short and straight, whereby the flow into the pump chamber can take place very rapidly and with virtually no pressure drop. Pumps with annular chambers can have large capacities and still have short filling times because of the large area of the inlet passage and the short filling length.

Filling of the pump chamber 16-1 takes place substantially "passively" - it takes place essentially only under action of the hydrostatic head pressure existing in the supply chamber 15-1 at the inlet passage 17-1, because within the pump chamber no suction is produced as a direct consequence of the downward movement of the displacement member 25-1; the displacement member has no force-transmitting connection with the element 12-1 which is effective in the direction of expansion of the pump chamber (downwardly).

It is within the scope of the invention to exert an influence on the filling by causing the pressure within a body of gas surrounding the pump chamber to vary in a particular way during the pump cycle. It is also possible to exert an influence on the filling by subjecting the inlet or the supply chamber to an external pressure.

As shown in Fig. 1B, the inlet passage 17-1 is then closed by an upward movement of the inlet valve member 23-1, and the outlet passage 18-1 is opened by a downward movement of the valve member 20-1. Then the displacement member 25-1 is moved upwardly to displace the lower wall of the pump chamber upwardly and thereby expel the liquid in the pump chamber 16-1 through the outlet passage 18-1 and the outlet connection 14-1. Meanwhile the supply chamber 15-1 is replenished from the inlet connection 13-1. The outlet passage 18-1 is then closed, the displacement member 25-1 is retracted downwardly, and the inlet passage 17-1 is opened again so that another pump cycle can be carried out.

A feature of the described pump resides in the combination of the annular inlet passage 17-1, the annular outlet passage 18-1 and the short filling length, which permit a very rapid filling of the pump chamber, even when the pressure on the inlet side is very low, and a very rapid emptying of the pump chamber. The pump can therefore pump a large volume of liquid per unit of time with small internal losses and, accordingly, with a very high efficiency. As long as the inflow to the pump do s not exceed the flow rate which corresponds to the product of the maximum stroke volume and the stroke rate, the pump, by virtue of its self-regulation, adapts the volume pumped for each stroke to the inflow. Within a fairly wide range of inflow rates through the inlet connection 13-1, therefore, the pump accommodates continuous inflow free of pressure pulses and interruptions. If the inflow should exceed the flow rate corresponding to the aforesaid product, the speed or stroke rate of the pump may be increased. Because of the small internal losses, the stroke rate can be raised to high levels.

A further feature, which is present in the described pump as well as in the pumps to be described and which contributes to rapid filling of the pump chamber 16-1, resides in the provision of a volumetric capacity of the supply chamber 15-1 which is sufficiently large - preferably substantially larger than that of the pump chamber 16-1 - to ensure filling of the pump chamber 16-1 without any substantial replenishment of the supply chamber 15-1 being necessary during the filling of the pump chamber. Thus, all of the liquid which enters the pump chamber 16-1 during the filling phase of the pump cycle, is immediately available close to the inlet passage 17-1 when the filling phase commences.

The element 12-1 is arranged in the pump housing 10-1/11-1 in a manner such that the supply chamber 15-1 can expand and contract freely within wide limits in dependence on, respectively, the inflow of liquid to the supply chamber and the outflow of liquid from the supply chamber to the

pump chamber 16-1.

The embodiment of Figs. 2A and 2B differs from that of Figs. 1A and 1B only in that the rollers 27-1 are omitted and the supply chamber 15-2 is open to the atmosphere. Thus, the pressure under which the filling of the pump chamber 16-2 takes place is determined by the difference in level between the inlet passage 17-2 and the free liquid surface in the supply chamber.

In the embodiment of Figs. 3A and 3B the supply chamber 15-3 is open as in Figs. 2A and 2B. Non-return or one-way flap or lip-type valves 23-3 and 20-3 are provided in, respectively, the inlet passage 17-3 and the outlet passage 18-3. Accordingly, the movable pinch valve members in the first two embodiments are replaced by portions of the housing member 10-3 which support the chamber element and define the passages 17-3 and 18-3. Each valve 23-3, 20-3 is formed of a pair of annular, axially opposed flaps of flexible material (e.g. plastic), which may also be slightly elastic, the outer edges of which are sealingly attached (e.g. by heat sealing), to the respective opposite element walls in the inlet passage 17-3 and which are free to deform and can thereby displace upwardly and downwardly at their inner edges.

When liquid is flowing inwardly in the inlet passage or in the outlet passage, the flaps are held in spaced relation without appreciably resisting the flow of liquid, but as soon as there is a tendency for the liquid to flow in the opposite direction, the flaps close the passage to block the flow. Insofar as the flaps are elastic, their elasticity is not so high that they are not capable of reliably withstanding the occurring pressures and there is, therefore, no danger of the flaps turning in the wrong direction. When the operating pressure of the pump is high, the flaps can be reinforced with a suitable material, such as glass fibers, to prevent them from inverting.

The flaps may be designed such that they contribute, by virtue of their elasticity, initial shape, or otherwise, to accelerate the flow of liquid as they are opened. Moreover, they may be somewhat biassed towards closed or open position.

In a modified embodiment, which is not shown, one of the valves or both may combine a pinch valve of the type shown in Figs. 1 and 2 with a flap. In such case, the pinch valve preferably is arranged to close the associated passage only incompletely, leaving it to a flap to complete the closing.

As shown in Figs. 3A and 3B, the flap valves are formed by a flap element separate from the chamber element walls. However, the flaps may advantageously also be formed of a fold in the sheet or film material of which the element is made, the forming of this fold taking place during the fabrication of the chamber element. The last-mentioned design lends itself to production by means of known techniques for the manufacture of elements and other objects of plastic (vacuum forming and blow moulding). The same design may also be adopted in the embodiments described hereinafter.

The embodiment shown in Figs. 4A and 4B is similar to that of Figs. 1A and 1B except in that the outlet valve is in the form of a non-return or one-way valve 20-4 of the flap or lip type disposed in the outlet connection 14-4 and in that the displacement member 25-4 is disc-shaped or plate-shaped (mushroom shape). In this case, the pump chamber 16-4 is disc-shaped in plan view, rather than annular as in the foregoing embodiments. Also, the outlet passage 18-4 (Fig. 4B) is formed only near the end of the pumping stroke, which is somewhat different in form and function from the previous embodiments.

The embodiment shown in Figs. 5A and 5B differs from that of Figs. 4A and 4B in that the rollers for the agitation of the liquid in the supply chamber 15-5 are omitted, in that the inlet valve 23-5 comprises a single annular flap of flexible material which is attached along its outer edge to the lower element wall and movable to a position in sealing engagement with the upper element wall under action of pressure within the pump chamber 16-5, and in that the valve in the outlet duct is omitted.

It has been found that a valve that closes to block backflow in the outlet duct is not required in certain cases, namely, when the pump operates at high stroke rates. In such cases, the momentum of the outgoing liquid stream is sufficient to permit filling of the pump chamber 16-5 through the inlet passage 17-5, even though the pump chamber is open on the outlet side during intake.

Figs. 6A, 6B show an embodiment which is similar to that of Figs. 5A, 5B except in regard to the positioning and design of the outlet passage 18-6, the outlet connection 14-6 and the associated outlet valve 20-6.

The outlet connection 14-6 is radial in this case and is positioned in diametrically opposed relation to the inlet connection 13-6. Accordingly, it has its upstream end at the perimeter of the pump chamber 16-6, and like the inlet connection 13 6 it extends radially outwardly. Consequently, a portion, but only a portion, of the circumference of the element is not used for the supply chamber 15-6 and the inlet passage 17-6 but the latter can still be very long.

In this embodiment, the outlet valve 20-6 is a flap or lip similar to the inlet valve 26-3, and like the latter it is secured to one wall of the outlet passage 18-6 which is located at the junction be-

tween the pump chamber 16-6 and the supply chamber 15-6 (see Fig. 6C which is a plan view of the chamber element 12-6).

It may be advantageous in the embodiment shown in Figs. 6A, 6B, 6C to block or close the region of the supply chamber 15-6 adjacent the outlet connection. The wall of the supply chamber should then be shaped such that no pockets are formed in which the liquid being pumped may become stagnant or forced to undergo abrupt changes of its direction of flow in order to reach the outlet passage.

The outlet connection 14-6 of the embodiment of Figs. 6A, 6B, 6C need not necessarily be aligned with the inlet connection but may include a smaller or larger angle therewith. If desired, the two connections may even be disposed side by side and substantially parallel. It is essential, however, that the inlet passage 17-6 and its valve extend over the major portion of the circumference of the pump chamber.

Figs. 7A, 7B and 7C show an embodiment in which part of the annular supply chamber 15-7 is located closer to the center of the element than the gap-like inlet passage 17-7. In this case, the drive mechanism of the displacement member 25-7 is a ball-bearing screw-spindle mechanism - not shown in detail - the screw-spindle of which has a rotationally fixed connection with the rotor 28-7 of an electric motor disposed in the base member 10-7 of the pump housing.

As is evident from a comparison of Figs. 7A, 7B, 7C with one another, the movement of the displacement member 25-7 of this embodiment has a direct influence on the shape and volume of the supply chamber. Thus, as the displacement member moves downwardly ("drops"), see Fig. 7A, the volume of the supply chamber decreases, because the displacement member collapses the supply chamber, see Fig. 7C. The liquid in the supply chamber then flows into the pump chamber 16-7 together with the liquid entering the pump through the inlet connection 13-7. As the displacement member is driven upwardly and thereby reduces the volume of the pump chamber, see Fig. 7B, the supply chamber is enlarged and at the same time the inlet valve 23-7 is closed. The liquid which then enters by way of the inlet connection is accommodated in the supply chamber and then, upon the following downward movement of the displacement member, flows into the pump chamber as described.

The embodiment shown in Figs. 7A, 7B, 7C also has an outlet valve 20-7 that prevents backflow into the pump chamber 16-7 from the outlet connection 14-7. As shown in the figures, the outlet connection is parallel to and positioned diametrically opposite the inlet connection, but other orientations and positions can be envisaged.

The outlet valve 20-7 is an annular flap valve, one circumferential edge of which is secured to the top member 11-7 of the pump housing and the other, free circumferential edge of which is provided with a bead ring 29-7. This bead ring strengthens the free flap edge and in the closed position of the valve (Fig. 7C) sealingly engages the interior wall of the top member 11-7 of the housing. As an alternative to the illustrated design of the outlet valve, a spring-biassed vertically movable valve member may be provided which seals against an annular wall portion where the pump chamber merges with the horizontal outlet connection.

The inlet valve 23-7 of the embodiment shown in Figs. 7A, 7B, 7C is also an annular flap valve, which is secured to the displacement memb r and thus moves together with it. This arrangement results in a favourable flow pattern of the liquid flowing from the supply chamber into the pump chamber, but it is within the scope of the invention to secure the flap to the pump housing and arrange for its movable portion to cooperate with the displacement member.

As in the other illustrated and described embodiments in which the inlet valve is a lip or flap valve, the inlet passage 17-7 is opened to permit flow into the pump chamber with a very small pressure drop as soon as the pressure upstream from the valve only slightly exceeds the pressure on the downstream side. Similarly, the inl t passage is immediately closed when the pressure in the pump chamber only slightly exceeds the pressure on the upstream side of the valve. The rapid opening and closing of the flap valves is attributable to the annular configuration and the consequent large surface area of the valve over which the pressure acts. For the same reason, the outlet valve 20-7 and, accordingly, the outlet passage 18-7 are closed immediately when the pressure in the outlet connection 14-7 exceeds the pressure in the pump chamber at the beginning of the intake stroke.

Figs. 8A, 8B show a pump in which there are two displacement members 25-8A, 25-8B which operate in phase opposition to reduce the volumes of different sections of the pump chamber at different times.

One displacement member 25-8A resembles the displacement member shown in Figs. 4-6 and serves to reduce the volume of a central second stage chamber section 16-8A, which is similar to the pump chamber of Figs. 4-6 and communicates with a central outlet connection 14-8.

The other displacement member 25-8B is annular and concentric with the first-mentioned, central member. This annular, outer member serves to

reduce the volume of an annular, outer variable volume pump chamber section 16-8B which is concentric with the central second stage variable volume chamber section 16-8A.

At its radially inner side the outer pump chamber section 16-8B communicates with the central second stage chamber section 16-8A by way of an annular passage 30-8 in which a one-way flap valve 31-8 resembling the flap valve of Figs. 3 and 5 is provided to open to permit flow into the pump chamber section 16-8A. This passage constitutes both an inlet passage of the central pump chamber section 16-8A and an outlet passage of the outer pump chamber section 16-8B.

At its radially outer side the outer pump chamber section 16-8B communicates with an annular supply chamber 15-8, which is similar to the supply chamber of Figs. 2 and 3, by way of an annular inlet passage 17-8 having a one-way flap valve 23-8 which opens to permit flow into the outer pump chamber portion 16-8B and which likewise resembles the flap valve 23-3 and 23-5 of Figs. 3 and 5.

The two displacement members 25-8A and 25-8B are actuated substantially in phase opposition by mechanisms resembling the mechanisms employed for actuating the displacement member and pinch valve of Fig. 4. The maximum volumes of the pump chamber sections and the movements of the two displacement members are chosen such that the stroke volume of the outer pump chamber section 16-8B is approximately twice that of the central pump chamber section 16-8A.

Fig. 8A shows a phase of the operating cycle of the pump in which the outer displacement member 25-8B is moving downwardly and the outer pump chamber section 16-8B is being filled from the supply chamber 15-8 by way of the inlet passage 17-8 without any appreciable pressure drop across the latter, whereas the central second stage displacement member 25-8A is moving upwardly to expel liquid from the central second stage chamber section 16-8A, the flap valve 31-8 being held in closed condition by the pressure in the central chamber section.

In the phase shown in Fig. 8B, the state of affairs is reversed. Accordingly, the outer displacement member 25-8B is moving upwardly to expel liquid from the outer pump chamber section 16-8B into the central second stage chamber section 16-8A by way of the passage 30-8, whereas the central displacement member 25-8A is moving downwardly, allowing the central chamber section 16-8A to expand under action of the pressure the liquid exerts on its walls.

The volume of liquid expelled from the outer pump chamber section during the upward movement of the outer displacement member is larger than the increase of the volume of the central second stage chamber section. Consequently, liquid will be discharged through the outlet connection 14-8 also in this phase (Fig. 8B) of the operating cycle of the pump. Whereas inflow to the pump chamber takes place only in the phase in which the outer pump chamber section is expanding, the discharge of the pump takes place substantially continuously, albeit with some pulsation.

The embodiment shown in Figs. 9A, 9B is similar in structure and operation to that shown in Figs. 8A, 8B, except in that the externally powered mechanism for positively actuating the inner displacement member 25-9A in the upward direction is replaced with an adjustable spring mechanism 26-9A constantly urging this displacement member upwardly. During the upward stroke of the outer displacement member 25-9A, the central second stage displacement member 25-9A is moved downwardly under action of the fluid pressure within the central second stage chamber section 16-9A, thereby compressing the spring mechanism 26-9A, as shown in Fig. 9A. During the downward movement of the outer displacement member 26-9B, the energy stored in the spring mechanism moves the central displacement member upwardly as shown in Fig. 9A.

Figs. 10A, 10B are cross-sectional views corresponding to Figs. 8A, 8B and 9A, 9B of a further embodiment of a two-stage pump embodying the invention, and Fig. 10C is a plan view of the chamber element of this further embodiment.

The pump shown in Figs. 10A, 10B, 10C comprises two displacement members 25-10A and 25-10B which operate as described with reference to Figs. 9A, 9B. Accordingly, the displacement member 25-10B is associated with an externally powered drive mechanism for positively, or substantially positively, actuating it in the upward direction, whereas the displacement member 25-10A is associated with an adjustable spring mechanism 26-10A constantly urging it upwardly.

The two displacement members 25-10A and 25-10B and the associated pump chamber sections 16-10A and 16-10B of chamber element 12-10 are horizontally offset from one another, and the inlet valve 23-10 and the valve 31-10 between the pump chamber sections are flap valves similar to the valves 23-6 and 20-6 of Figs. 6A, 6B, 6C. Moreover, as shown in Fig. 10C, the inlet connection 13-10 and the outlet connection 14-10 are disposed side by side and substantially parallel.

Except for the different flow pattern resulting from the horizontally offset disposition of the chamber sections, the pump of Figs. 10A, 10B, 10C operates in substantially the same way as the pump of Figs. 9A, 9B.

In the embodiments illustrated and described above by way of example, the pump chamber 16

and the supply chamber 15 of the chamber element are circular or shaped as a circular ring and as is readily appreciated, the mechanical pump components have a corresponding shape. This shape is normally preferred, having regard to both fluid flow and manufacturing aspects, but it is within the scope of the invention for the pump to have a different configuration, such as a more or less oval or otherwise elongate configuration. An elongated configuration may be contemplated especially in the case shown in Figs. 6A, 6B, 6C where the inlet and the outlet are aligned.

Moreover, in the embodiments shown in Figs. 8A, 8B and Figs. 9A, 9B, the central displacement members 25-8A, 25-9A, may be annular like the outer members 25-8B, 25-9B. The open space within the central annular displacement member may then accommodate elements of the pump drive mechanism, for example, or may be used for other purposes. If in such a case the drive mechanism for the two displacement members 25-8A and 25-8B of Figs. 8A, 8B is designed such that the members can be actuated in unison, with a selected phase displacement (e.g. in phase opposition or push-pull fashion), or individually (only one of the parts is actuated), as desired, interesting possibilities of varying the features of the pump in respect of stroke volume and output flow characteristics are offered.

In some cases, such as when the pump is used as a blood pump, the displacement member may suitably be connected with the pumping mechanism such that some resilient yielding of the displacement member relative to the pumping mechanism under action of the pressure in the pump chamber is possible so that there is some "lagging" of the displacement member during the pressure or delivery stroke. The motion of the displacement member which is initially lost as a consequence of the "lagging" is "recovered" at the end of the pressure stroke and may be utilized to ensure that the liquid does not become stagnant in the pump chamber, e.g. beneath the valve flap 31-8 of Figs. 8A, 8B. Such an arrangement may also be utilized to suppress any pressure waves tending to develop at the end of the delivery stroke.

A pump of the type of Figs. 8A, 8B with two or more displacement members and pump chamber sections, which preferably are annular, is also useful as a two-stage (multistage) compressor, particularly for the purpose of compressing large amounts of air to a relatively low pressure. A feature of compressors constructed in this manner is that only a single valve is required between the stag s; each valve functions both as an outlet valve of a radially outer or lower stage and as an inlet valve of a radially inner or higher stage. The other embodiments are also useful as compressors or air (or other gas) pumps, but they are believed in practice to be best suited as liquid pumps.

As is apparent from the drawings, a feature of the pump according to the invention is that the liquid being pumped has a favourable flow pattern, because it can pass through the pump without any abrupt changes of direction having to be imposed on it. Particularly advantageous in this respect are the embodiments of Figs. 1-6 and 8-10 where the height of the pump chamber is very small in comparison with the diameter and the liquid accordingly flows substantially horizontally up to the outlet connection. The generally low or flat shape of the pump chamber also permits a short length of stroke, meaning that the stroke rate may be high. In conjunction with the large flow cross-sectional area that the inlet passage and the outlet passage may have, this feature ensures a very low internal flow resistance of the pump.

In the embodiments of Figs. 5-10, the use of single-flap valves which are attached to the lower wall of the chamber element 12 and which are movable upwardly, in the direction of the fluid expelling movement of the displacement m mber, to a position in sealing engagement with the upper wall is advantageous in that the flow of fluid produced by the displacement member sweeps the lower side of the flaps. This sweeping flow minimizes the danger of any portion of the fluid being pumped becoming stagnant below or behind the valve flaps. Accordingly, those embodiments are particularly suitable for pumping blood, because they meet the very important requirement of blood pumps of being free of stagnant regions.

In the embodiments through which the invention has been exemplified in the drawings, the displacement member and its drive mechanism are positioned beneath the pump chamber. This positioning is preferred in most cases, especially when, as in the illustrated embodiments, a separat , readily replaceable chamber element of plastic film or sheet provides the surfaces which the fluid being pumped contacts during its passage through the pump. However, in some cases it may be preferred that the displacement member constitutes, or acts on, the top wall of the pump chamber and that the drive mechanism is positioned above the pump chamber. Moreover, it is conceivable to have a common drive mechanism for two opposed pumps stacked one above the other and operating in phase opposition. It is also possible to have two drive mechanisms for a single pump chamber, one drive mechanism on each side, working in opposition.

The chamber 16-10A and the spring-biased displacement member 25-10A of the embodiment of Figs. 10A, 10B, 10C can be used in conjunction with the outlets of single stage pumps of other

designs as a one-way valve and as a device for smoothing the pulsating outflow of the pump. In the case of blood pumps, such an arrangement provides a one-way outlet valve free of stagnant regions and a compliance volume downstream from the valve.

Claims

1. A positive displacement pump that includes means defining a supply chamber for receiving the fluid to be pumped, means defining a variable volume pump chamber, an inlet passage through which the fluid is conducted from the supply chamber to the pump chamber, an outlet through which the fluid is discharged from the pump chamber, a displacement member associated with the pump chamber and movable in opposite directions along a predetermined path such as to move through a variable displacement zone of the pump chamber to increase and decrease alternately the volume of the chamber, drive means for moving the displacement member in at least a direction to decrease the volume of the pump chamber, and inlet valve means for closing the inlet passage to block fluid backflow out of the pump chamber through the inlet passage, **characterised** in that the supply chamber (15) is disposed generally laterally of and substantially surrounds the displacement zone of the pump chamber (16) and the inlet passage (17) is substantially coextensive with the supply chamber (15) and opens to the pump chamber (16) through an elongated gap-like opening in a bounding wall of the pump chamber (16) located generally laterally of the displacement zone, whereby fluid may enter the pump chamber (16) through the inlet passage (17) substantially without any pressure drop.

2. A pump according to claim 1, **characterised** in that the pump chamber (16) includes a movable wall member that is engageable by the displacement member (25) on the delivery stroke and disengageable from the displacement member during the intake stroke so that the stroke volume of the pump is established by the supply of fluid from the supply chamber (15).

3. A pump according to claim 1 or 2, **characterised** in that the pump chamber (16) is generally round.

4. A pump according to any one of claims 1 to 3, **characterised** in that the dimensions of the pump chamber (16) transverse to the direction of movement of the displacement member (25) are substantially greater than the dimensions in said direction of movement.

5. A pump according to any one of claims 1 to 4, **characterised** in that the outlet (14) is located substantially in the center of a transverse stationary wall of the pump chamber (16) opposite from the displacement member (25).

6. A pump according to any one of claims 1 to 5, **characterised** in that the supply chamber (13) is adapted to receive a continuous inflow of the fluid being pumped and to discharge at least a portion of its contents into the pump chamber (16) through the inlet passage (17) when the inlet valve means (23) is open while collecting a reservoir of the fluid when the inlet valve means is closed.

7. A pump according to claim 2, **characterised** in that the movable wall member of the pump chamber (16) is formed of a flexible material and is deformed and displaced by the displacement member (25) during at least a portion of the delivery stroke of the pump.

8. A pump according to claim 7, **characterised** in that the movable wall member forms a part of the laterally bounding wall of the pump chamber (16) and defines one wall of the inlet passage (17), and wherein the valve means includes a pinch valve member (23-1,23-2) engaging said laterally bounding wall part and movable so as to move said bounding wall part across the opening and thereby close the inlet passage, and drive means (24-1,24-2) for periodically moving the pinch valve member across the opening.

9. A pump according to claim 3, **characterised** in that the inlet valve means includes a substantially annular flap (23) of flexible material fastened along one edge to a wall of the inlet passage (17) and having its other edge free for movement to an open position to allow inflow of fluid into the pump chamber (16) and to a closed position in engagement with the other wall of the inlet passage to stop backflow of fluid from the pump chamber through the inlet passage.

10. A pump according to claim 3, **characterised** in that the inlet valve means (23-3) includes a first annular flap of flexible material fastened along one edge to one wall of the inlet passage (17-3) and a second annular flap of flexible material fastened along one edge to the other wall of the inlet passage, both flaps having their other edges free for movement to an open position to allow inflow of fluid into the pump chamber (16-3) and to a closed position in engagement with each other to stop backflow of fluid from the pump chamber (16-3) through the inlet passage (17-3).

11. A pump according to any one of claims 1 to 10, **characterised** in that the supply chamber (15) and pump chamber (16) are defined by first and second spaced-apart wall members, at least one of which wall members is formed of a flexible material and includes a first portion engageable and displaceable by the displacement member (25) to vary the volume of the pump chamber (16) and

a second portion that defines one wall of the inlet passage (17).

12. A pump according to claim 11, **characterised** in that the valve means includes a pinch valve member engaging said second portion of said one wall member, drive means for cyclically moving the pinch valve member only part way across the inlet passage, and a flexible flap valve strip attached to the other wall of the inlet passage and having a free edge movable for engagement with said second portion of said one wall member in response to fluid pressure in the pump chamber.

13. A pump according to claim 11, **characaterised** in that the lateral bounding wall of the pump chamber (16) is generally round and the supply chamber (15) is generally annular and entirely surrounds the pump chamber.

14. A pump according to claim 11, **characterised** in that both the supply chamber (13-1,13-2,13-3)and pump chamber (16-1,16-2,16-3) are annular and the outlet from the pump chamber is an annular opening (18-1,18-2,18-3) located at an intemal boundary of the pump chamber generally laterally of the displacement zone.

15. A pump according to claim 14, **characterised** by an outlet valve that includes a movable valve member (20-1,20-2) engaging a third portion of the flexible wall member and drive means (22-1,22-2) for moving the valve member reciprocably to displace said third portion of the flexible wall member into and out of engagement with an opposite edge of the outlet opening (18-1,18-2) to close and open it.

16. A pump according to claim 11, **characterised** in that the flexible wall member of the pump is the lower member and further comprising means (10,27) for supporting a fourth portion of the flexible wall member that forms the lower wall of the supply chamber (15).

17. A pump according to claim 16, **characterised** in that the means for supporting the fourth portion of the flexible wall member includes one or more rollers (27-1,27-4) and means for rotating the rollers in an orbital path along the supply chamber (15-1,15-4) to agitate continuously the fluid in the supply chamber.

18. A pump according to claim 17, **characterised** in that the means for supporting the fourth portion of the flexible wall member is a rigid stationary member (10).

19. A pump according to any one of claims 1 to 18, **characterised** in that there is an outlet valve means (20) in the outlet (14).

20. A pump according to any one of claims 1 to 19, **characterised** by a second stage variable volume chamber (16-8A,16-9A,16-10A) in communication with the outlet (14-8,14-9, 14-10) from the pump chamber (16-3,16-9B,16-10B) so that it receives fluid discharged from the pump chamber, a one-way valve (31-8,31-9,31-10) in the outlet from the pump chamber to block fluid backflow from the second stage chamber into the pump chamber, a discharge passage leading from the second stage chamber, a second stage displacement member (25-8A,25-9A,25-10A) movable to increase and decrease alternately the volume of the second stage chamber, and drive means (26-8A,26-9A,26-10A) for moving the second stage displacement member in at least a direction to decrease the volume of the second stage chamber.

21. A pump according to claim 20, **characterised** in that the drive means includes a source of external energy.

22. A pump according to claim 20, **characterised** in that the drive means for the second stage displacement member is a spring that stores energy when the volume of the second stage chamber is increased by inflow of fluid from the pump chamber and releases the stored energy when there is no inflow from the pump chamber into the second stage chamber.

23. A pump according to any one of claims 20 to 22, **characterised** in that the stroke volume of the pump chamber (16-8B,16-9B,16-10B) is about twice the stroke volume of the second stage chamber (16-8A,16-9A,16-10A).

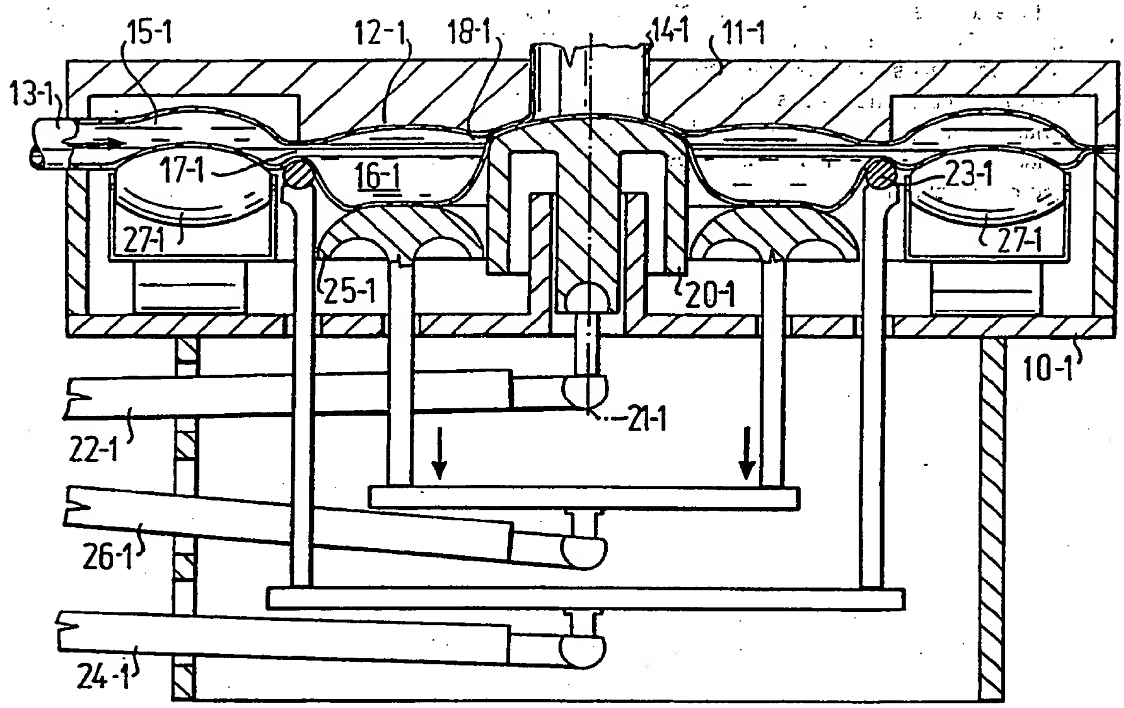
24. A pump according to any one of claims 20 to 23, **characterised** in that the pump chamber (16-8B,16-9B) is substantially annular and the second stage chamber (16-8A,16-9A) is substantially round and is located generally laterally of and is surrounded by the pump chamber.

25. A pump according to any one of claims 20 to 24, **characterised** in that the supply chamber (15-10) is substantially annular, the pump chamber (16-10B) is substantially round, the outlet is a passage leading generally laterally from the pump chamber and the second stage chamber (16-10A) is substantially round and is disposed laterally of and proximate to the pump chamber.

26. A pump according to any one of claims 1 to 25, **characterised** in that the volumetric capacity of the supply chamber (15) is at least as large as that of the pump chamber (16).

27. A chamber element for a positive displacement pump comprising first and second sheets of a flexible material joined at their perimeters in sealed relation and permanently formed to define a generally annular supply chamber (15), a generally round pump chamber (16) within the supply chamber and an inlet passage (17) forming an elongated gap-like opening at the juncture of the supply chamber with the pump chamber, an outlet opening (14) in one wall of the pump chamber and an intake opening (13) in at least one wall of the supply chamber.

28. A chamber element according to claim 27, **characterised** in that the inlet valve is an annular flap (23) of flexible material joined along one of its edges to one of the sheets adjacent the inlet passage (17) and having its other edge free, whereby the flap leaves the inlet passage open in the absence of fluid back-pressure from within the pump chamber (16) and deflects to close the inlet passage in response to fluid back-pressure from within the pump chamber.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24-1

FIG.1A

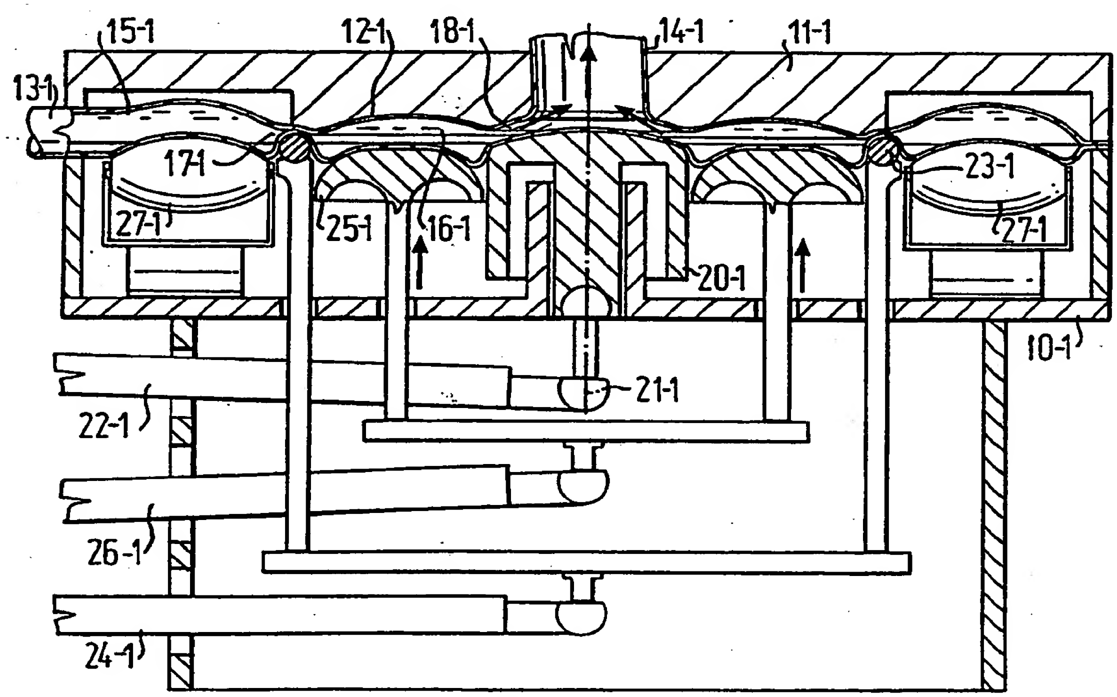
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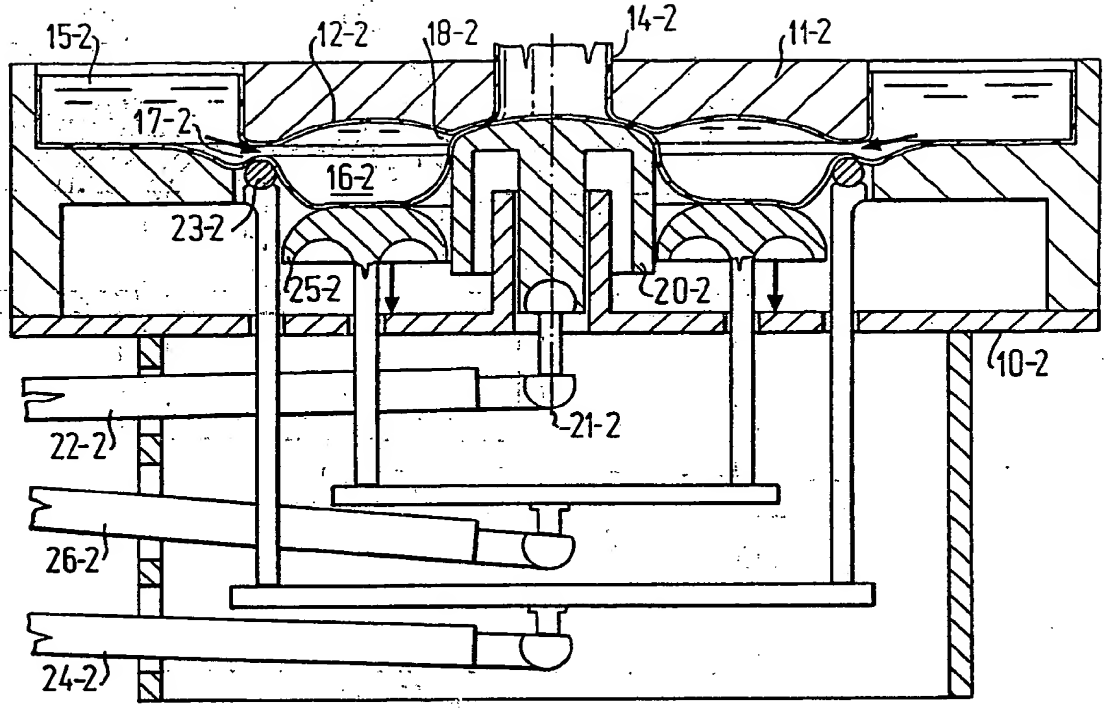
FIG.1B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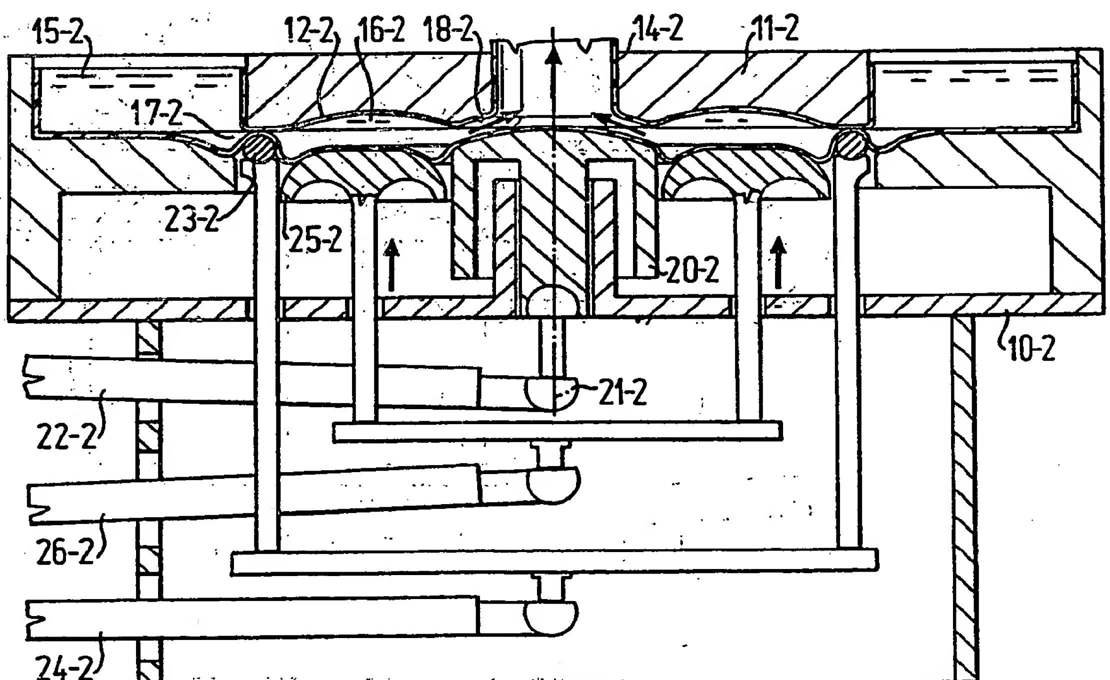
24-2

FIG.2A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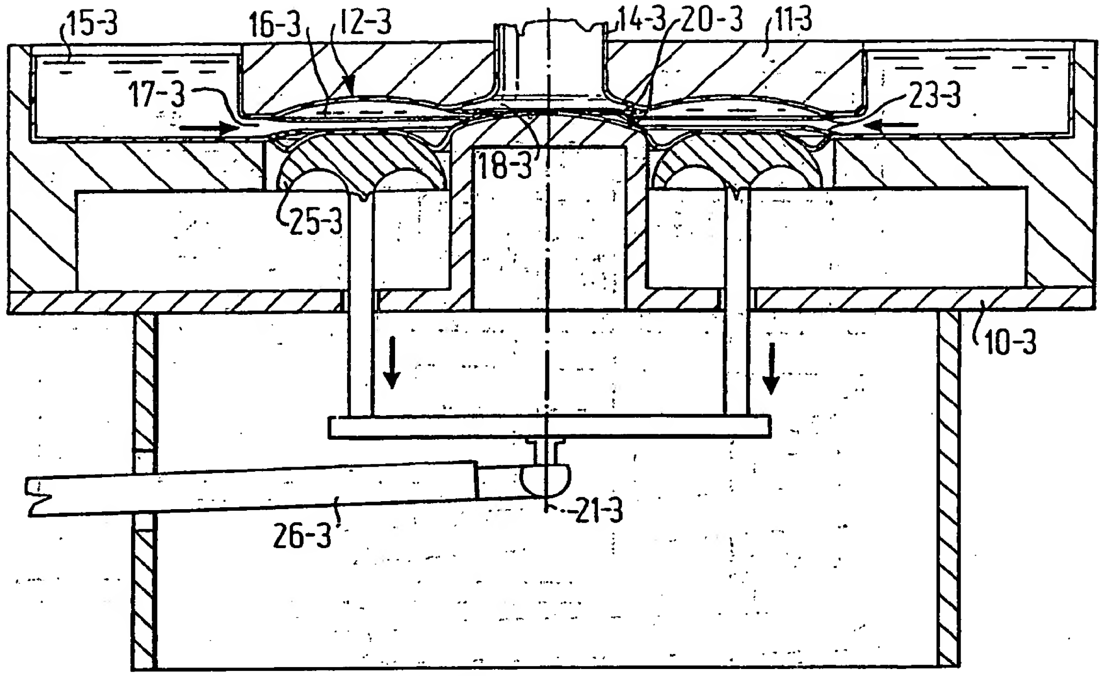
24-2

FIG.2B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26-3

FIG. 3A

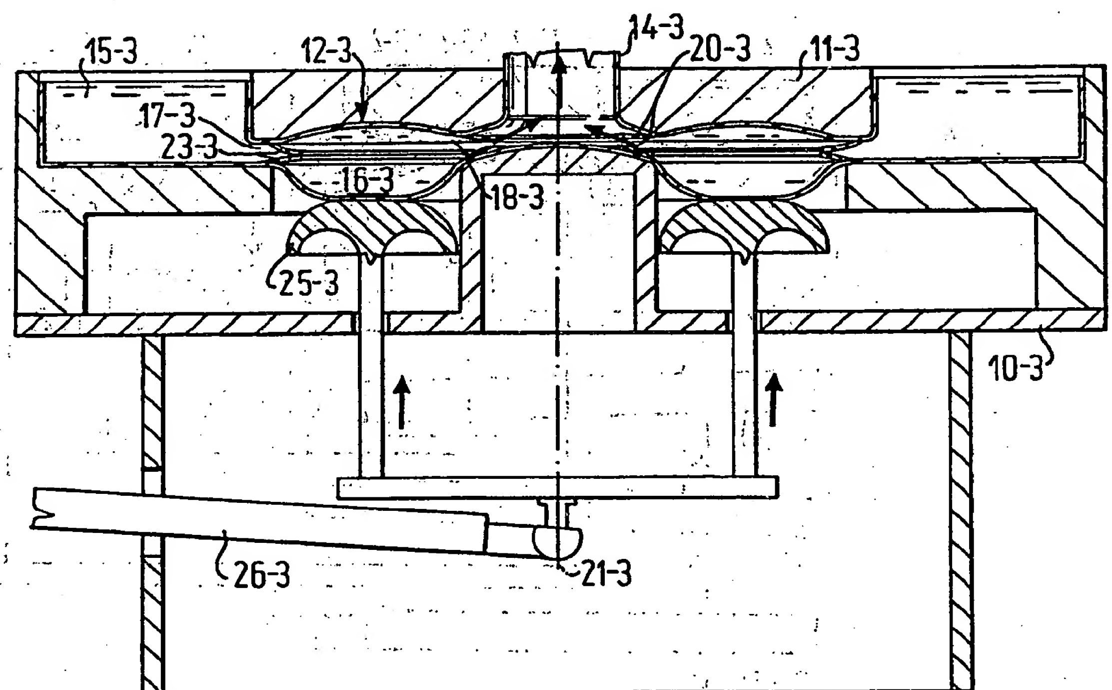
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FIG.3B

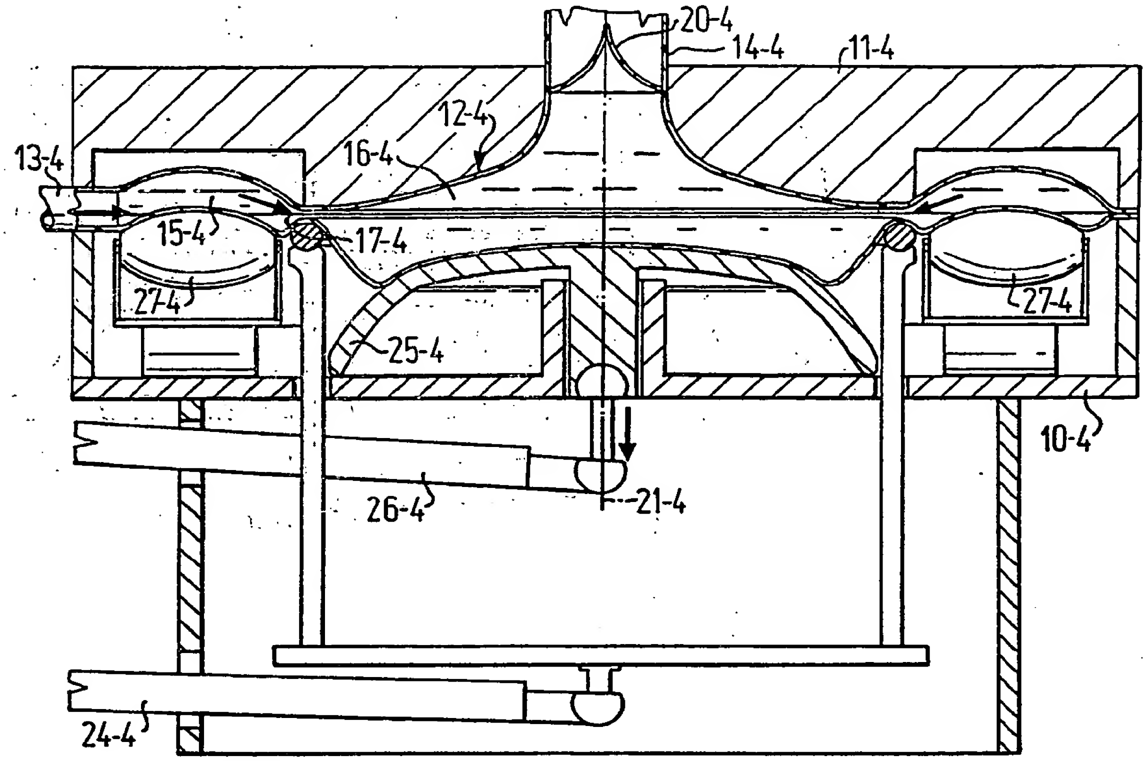
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FIG. 4A

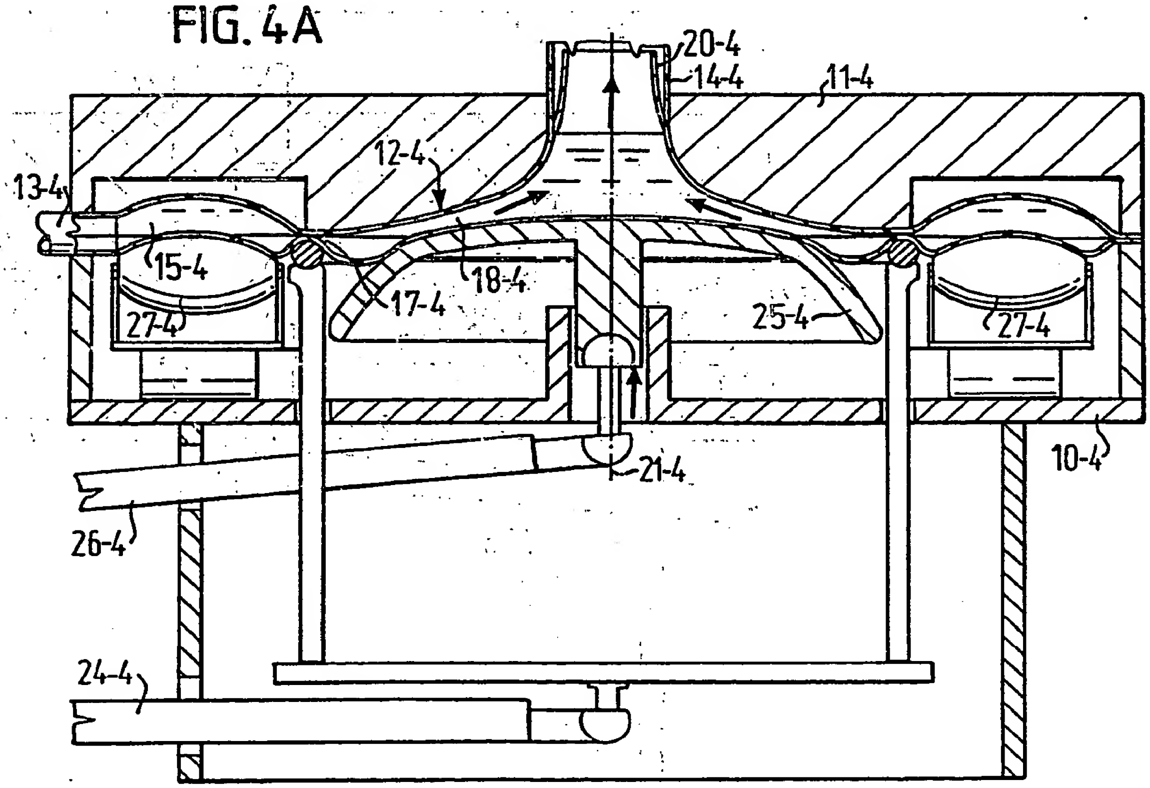
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FIG. 4B

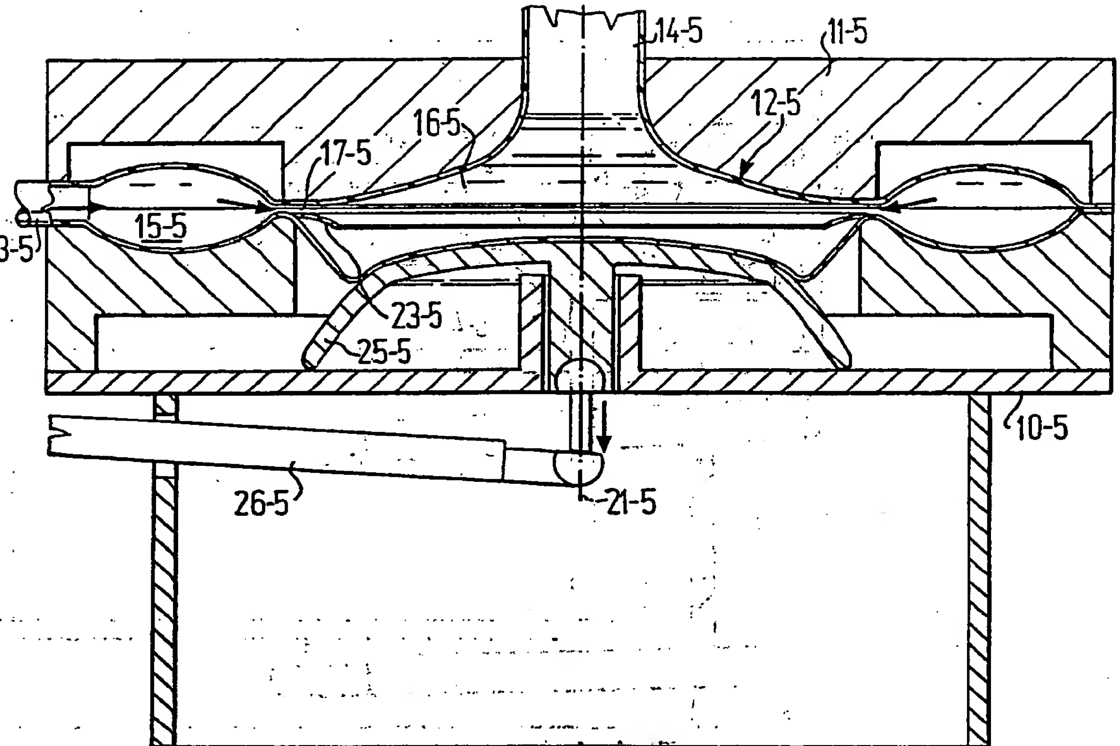
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FIG.5A

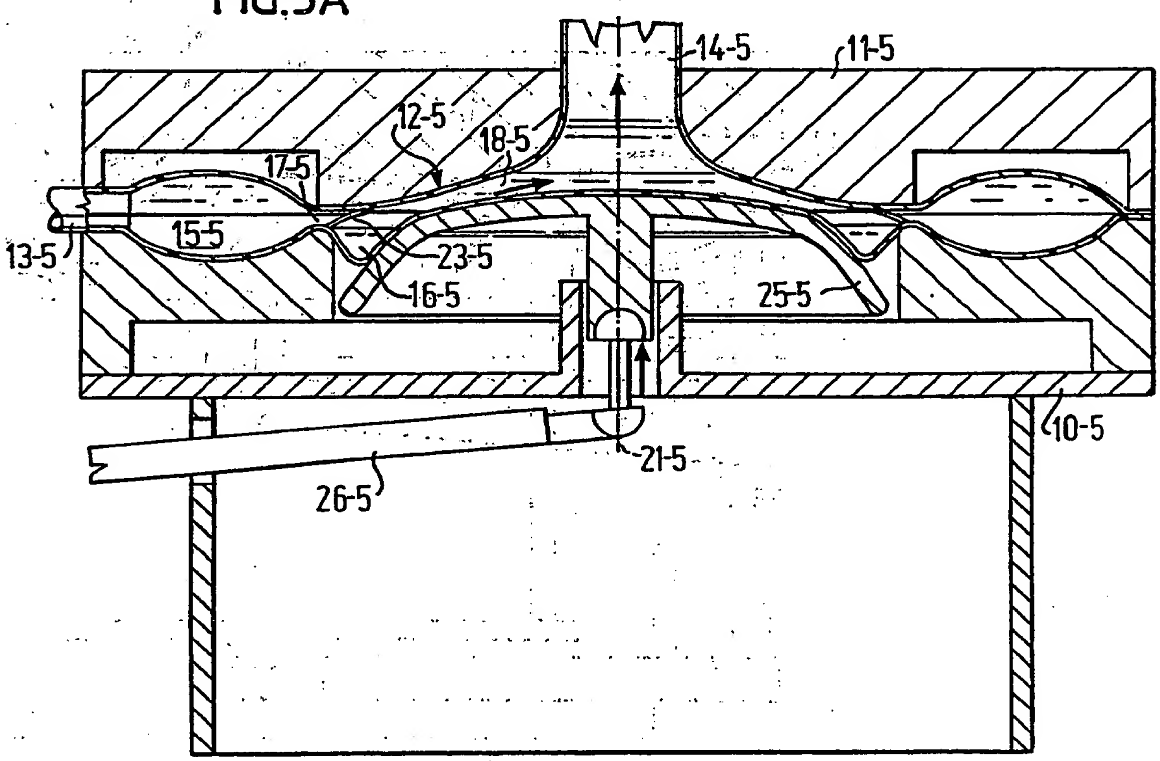
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FIG.5B

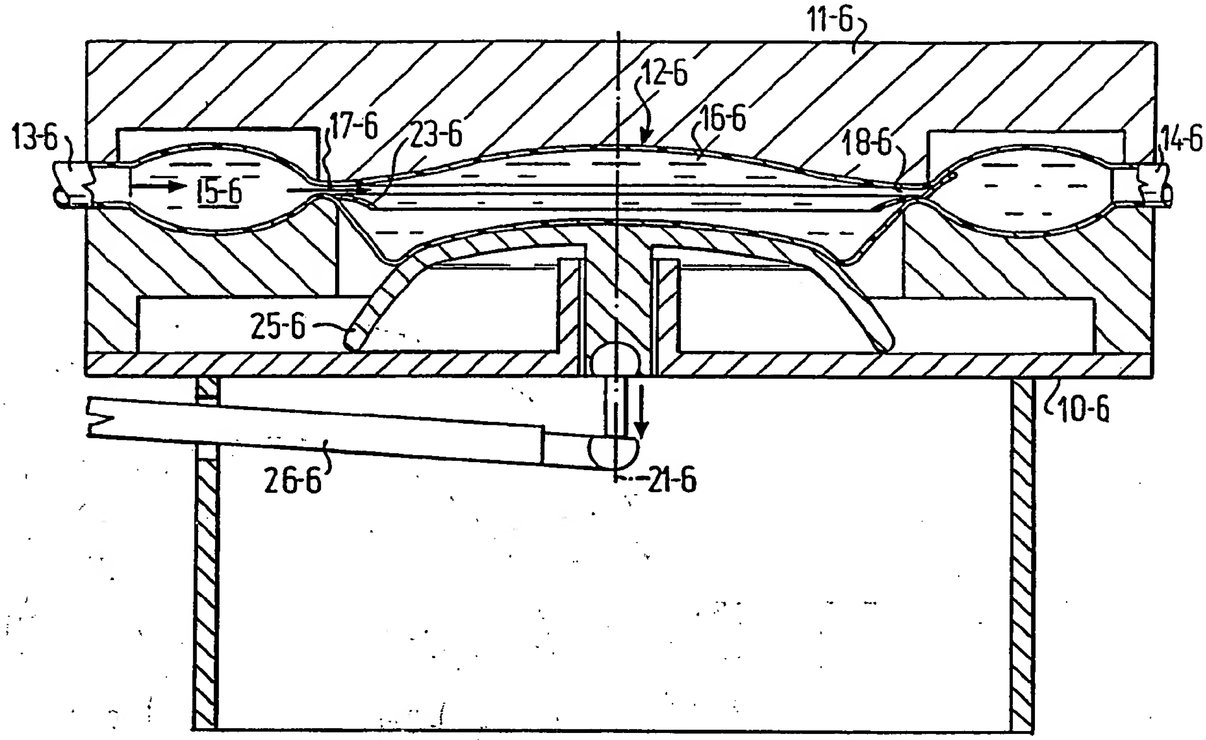
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FIG.6A

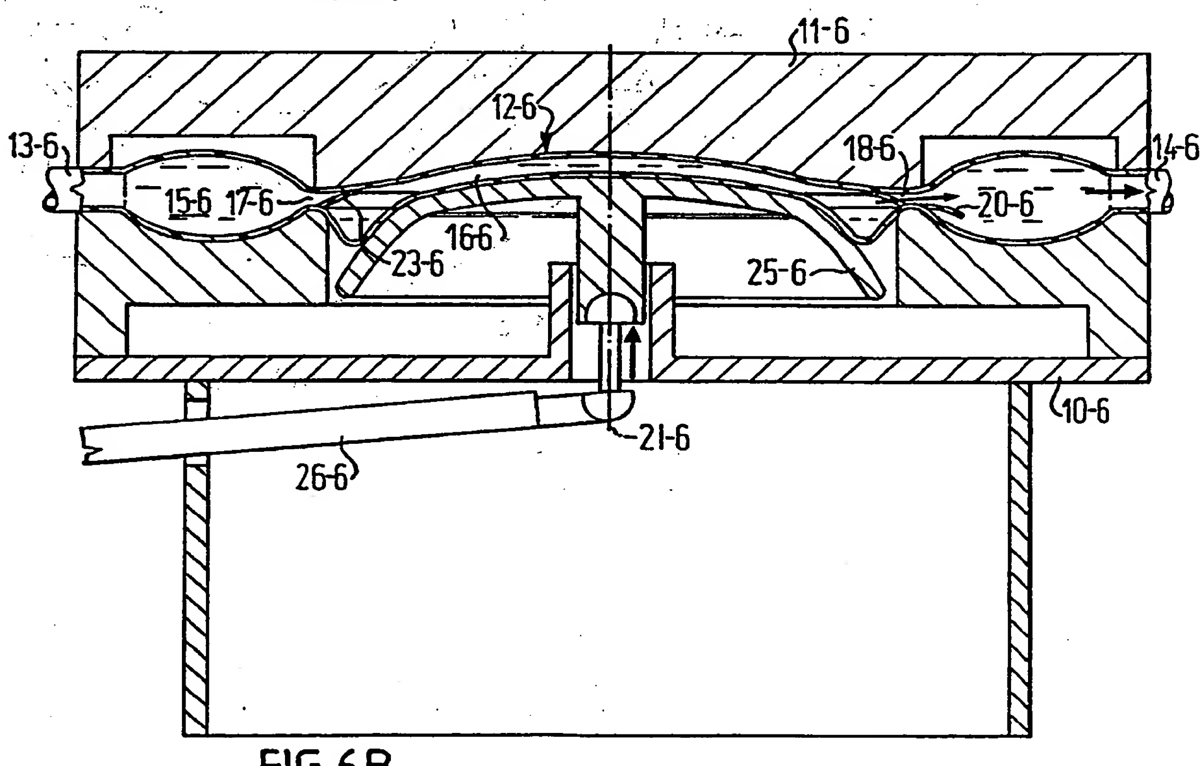
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FIG.6B

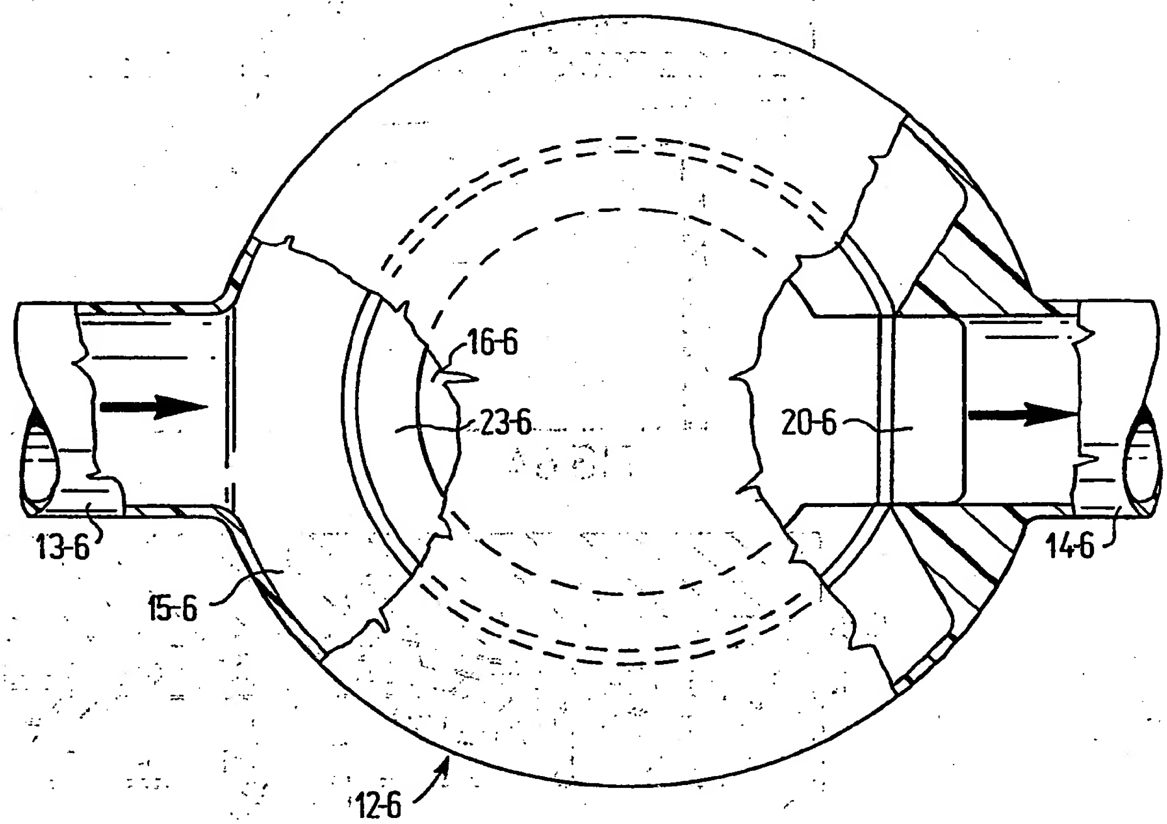

FIG. 6C

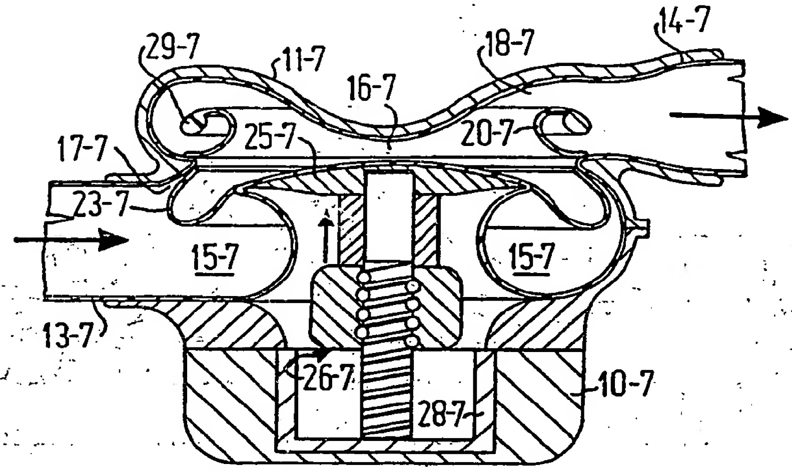

FIG. 7B

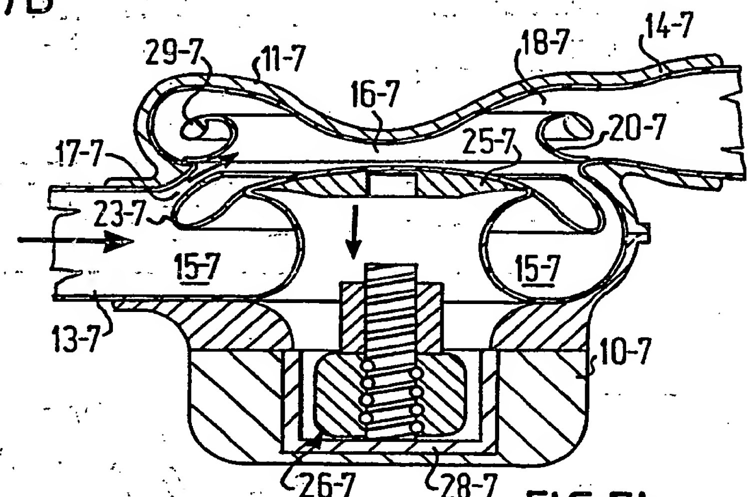

FIG. 7A

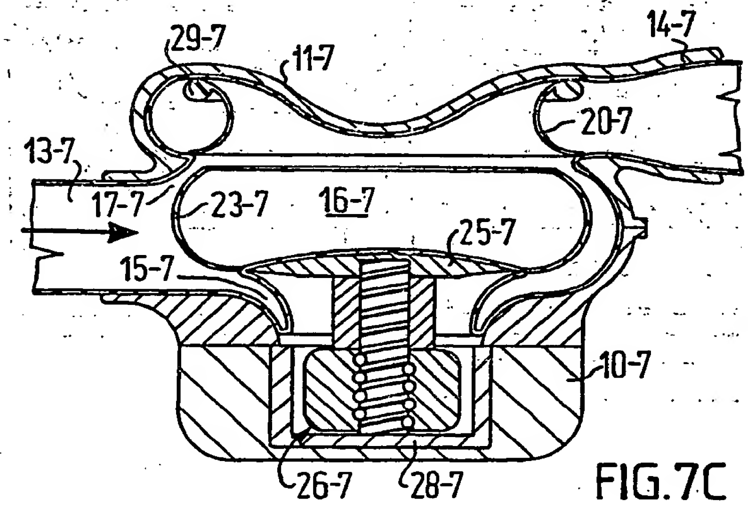

FIG.7C

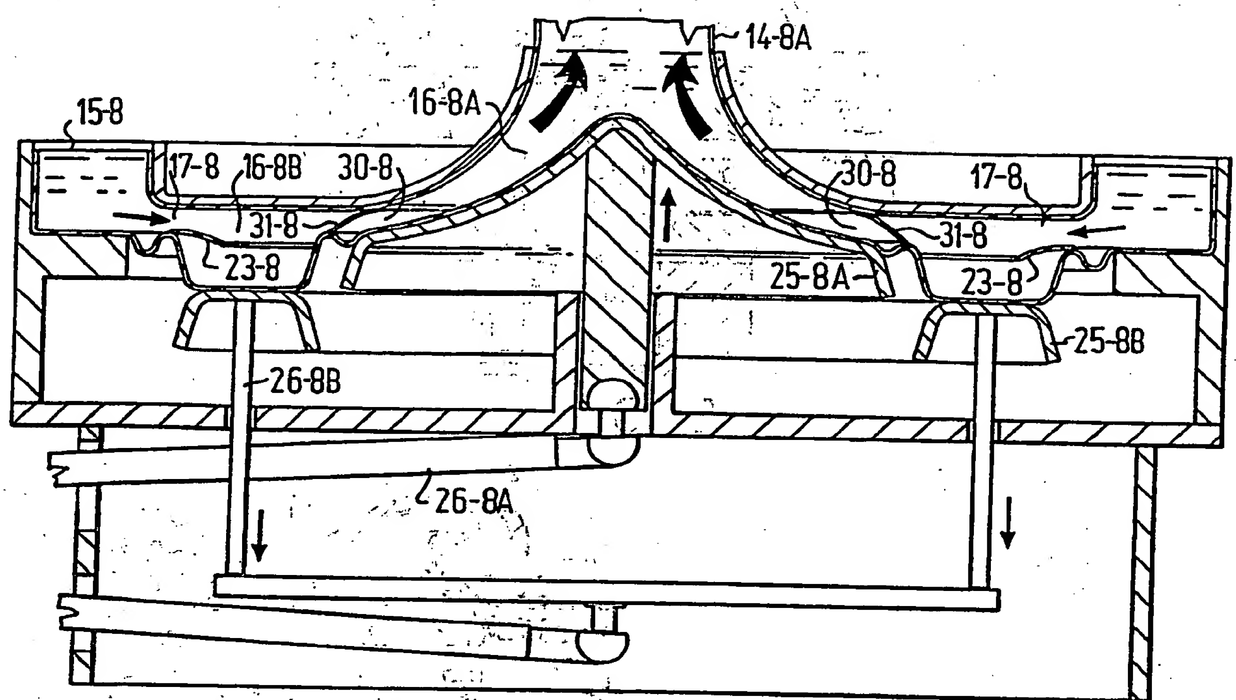
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FIG.8A

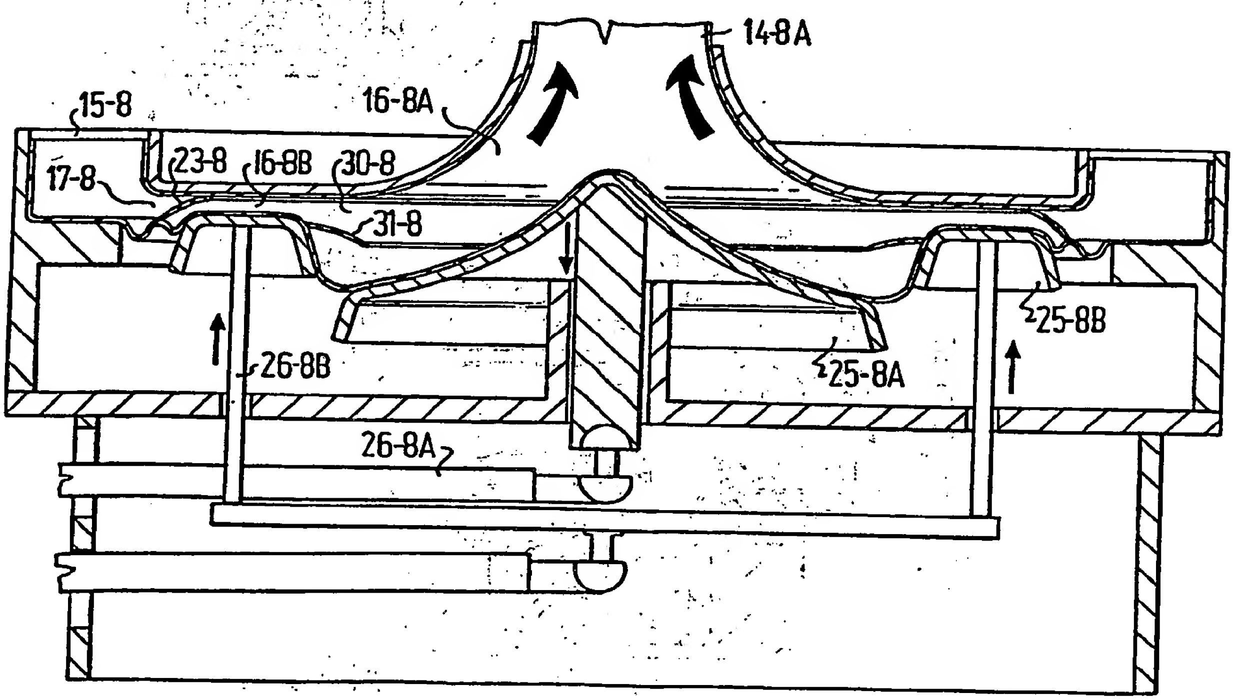
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FIG.8B

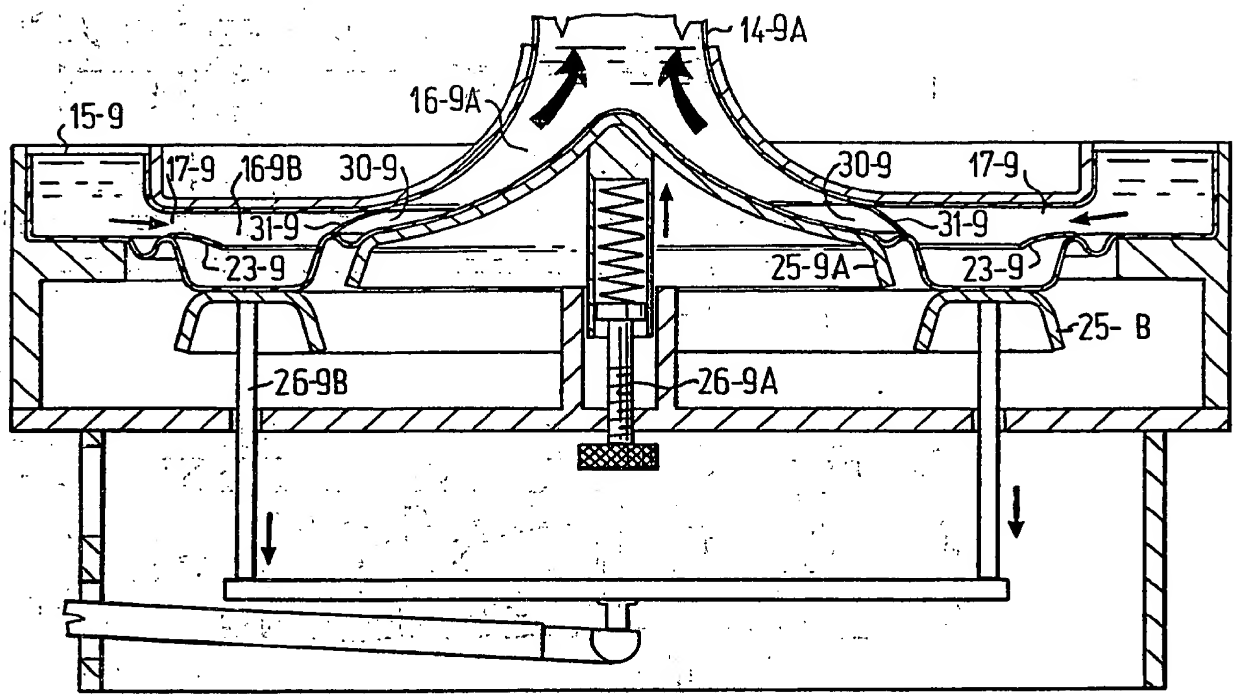
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FIG.9A

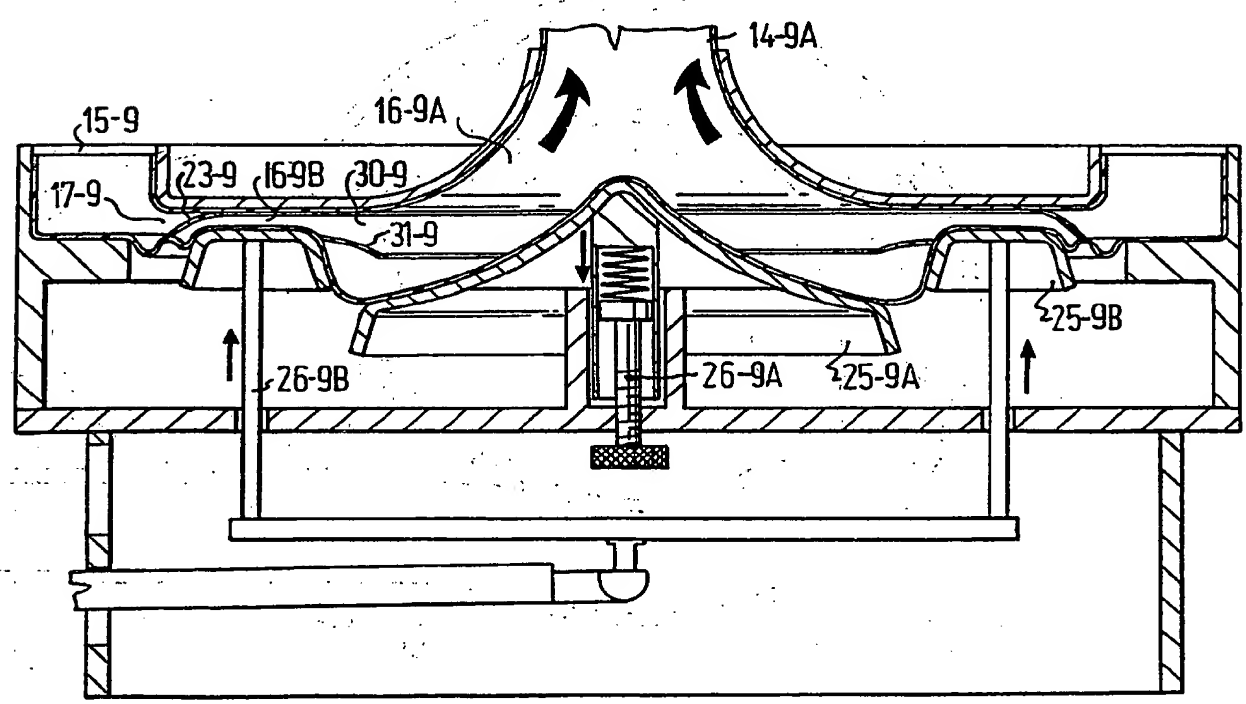
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FIG.9B

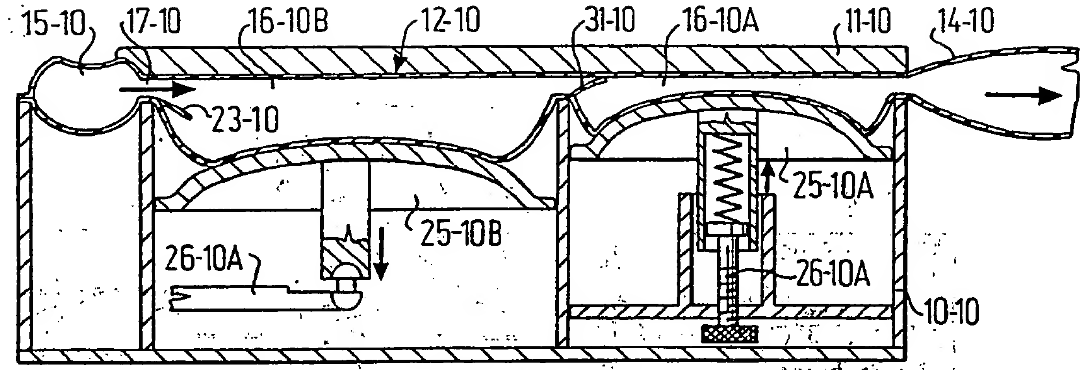

FIG.10A

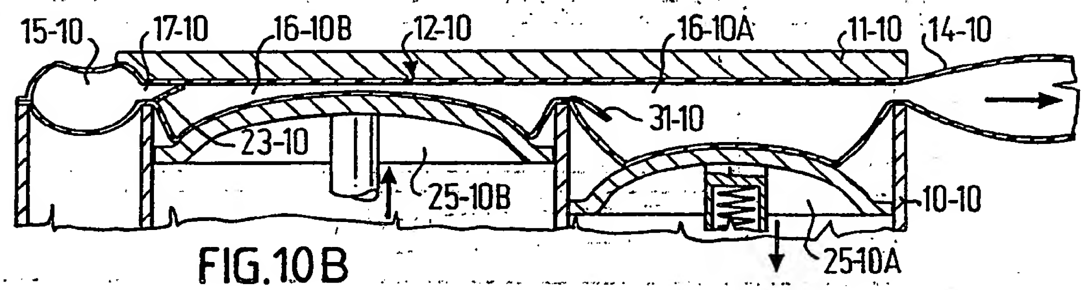

FIG.10B

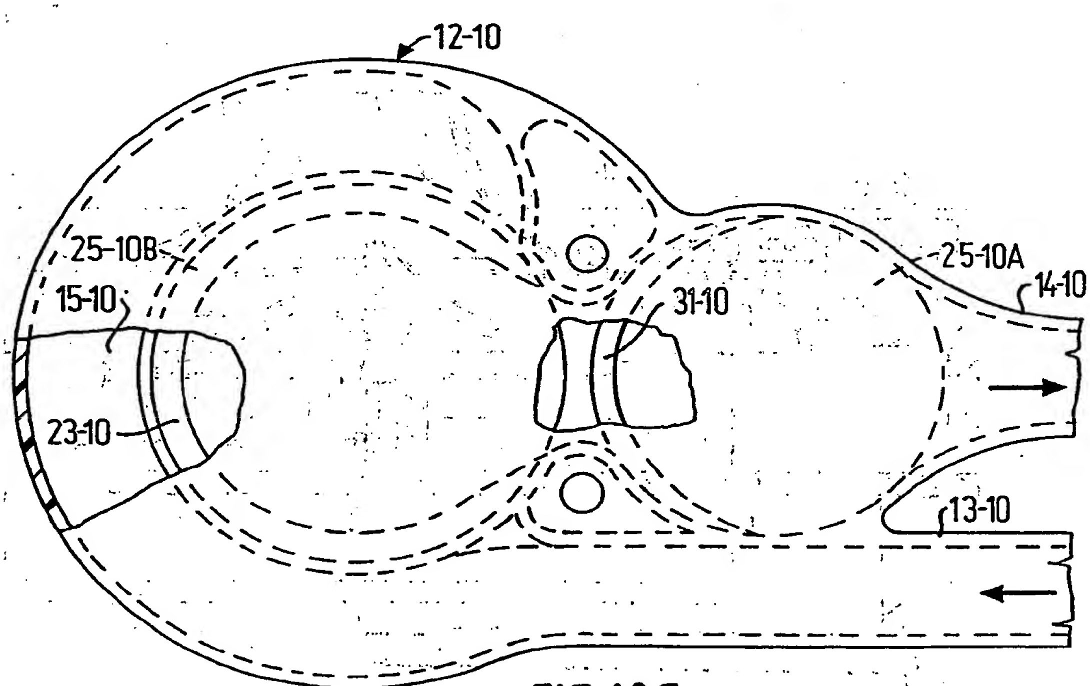

FIG.10C

European Patent Office

EUROPEAN SEARCH REPORT

Application number
EP 89850427.9

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int Cl 4)
X	DE-C-875 142 (MESSERSCHMITT AG) * Whole document * -----	1-12	F 04 B 43/02

TECHNICAL FIELDS SEARCHED (Int. Cl.4)

F 04 B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
STOCKHOLM	27-02-1990	SÖDERLING S.

CATEGORY OF CITED DOCUMENTS

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D : document cited in the application
L : document cited f r other reasons
& : member of the same patent family, c rresponding document

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